


219 CONF Paper / 10/16

43P

Pathfinder Program

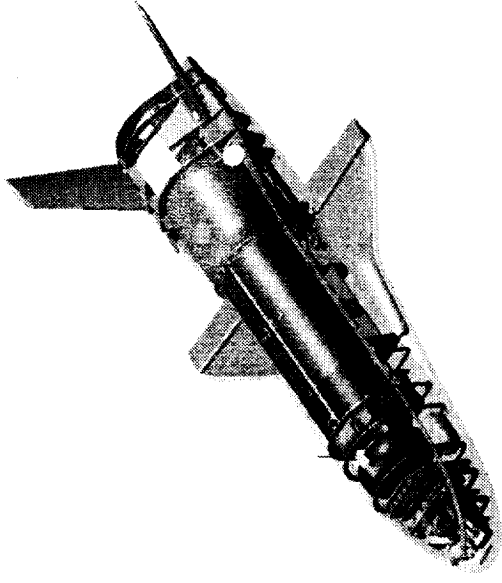
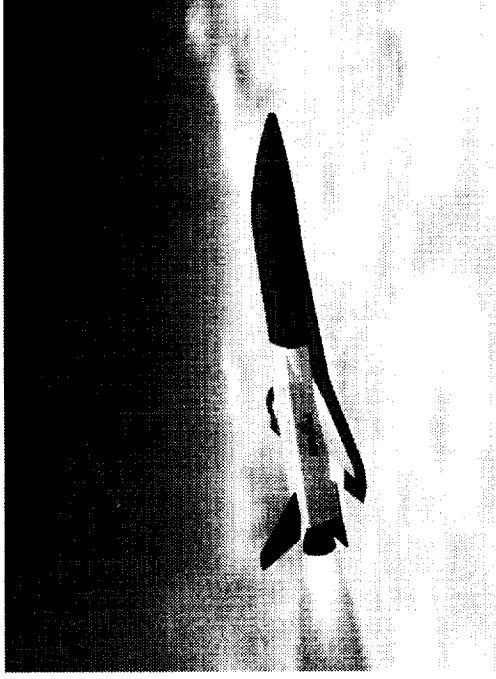


Presented at
Space Transportation Day
October 11, 2000
John R. London III
Marshall Space Flight Center, AL

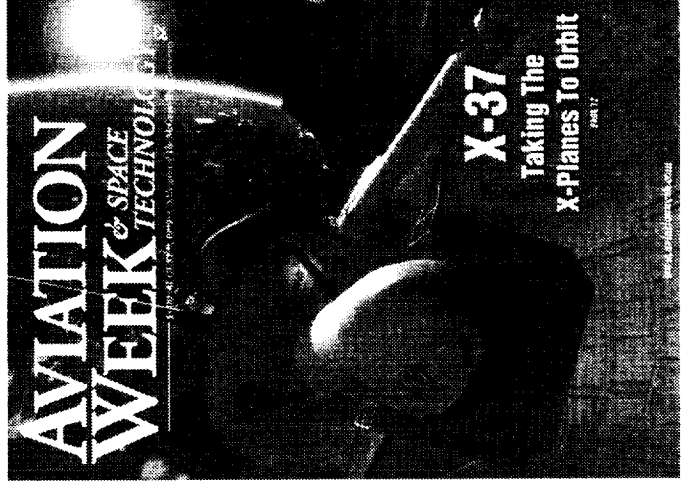
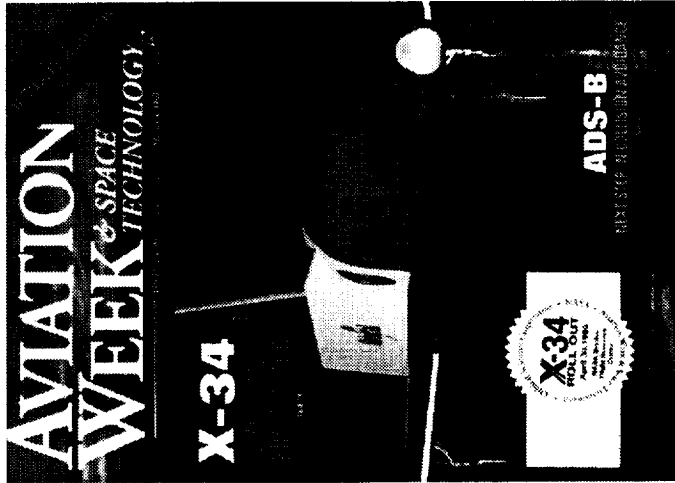
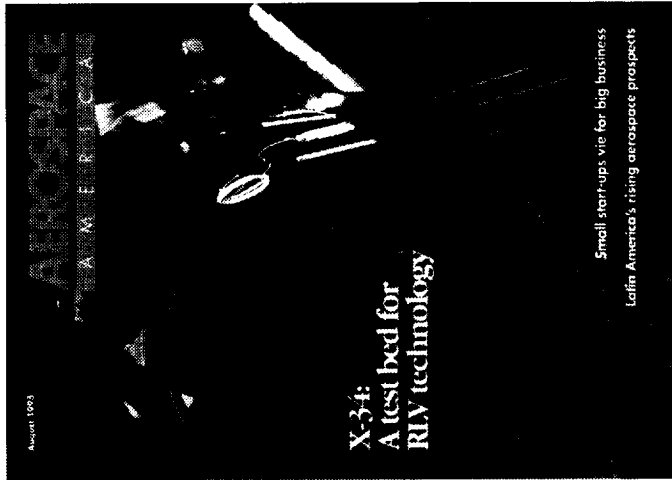
Program Overview



- **RLV Goal: to Significantly Reduce the Cost of Access to Space**
- **X-34 Project Objectives**
 - Test Bed Vehicle for Demonstrating Key Reusable Launch Vehicle (RLV) Operations and Technologies
 - Focus Areas
 - ◆ **Investigation of New Methods for Low-Cost Operations**
 - ◆ **New RLV Technologies Embedded in Vehicle Design**
 - ◆ **Demonstration of Hosted RLV and Hypersonic Experiments**
- **X-37 Project Objectives**
 - Test Bed Vehicle for Demonstrating RLV In-Space and Re-Entry Technologies and Flight Experiments
 - Focus Areas
 - ◆ **Investigation of New Methods for Design and Manufacturing**
 - ◆ **New RLV Technologies Embedded in Vehicle Design**
 - ◆ **Demonstration of Hosted RLV and Re-Entry Experiments**



High Visibility Flight Projects



X-34:

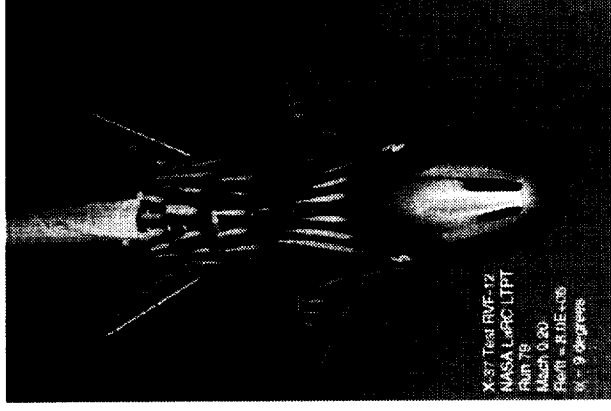
- Completed the build of A-1A at Dryden utilizing government technicians
- Issued a NTE contract change to OSC to include operations at White Sands & Dryden for unpowered and powered flights respectively
- Completed the report on the Risk Assessment in support of the Environmental work
- Vehicle system level testing on A-1A 90% complete
- First powered flight vehicle essentially complete (A-2)
 - Delivered the 2nd flight wing
- Participated in Fastrac/MPS and avionics/flight controls independent reviews January-March 2000
- Completion of A-2 Static Loads Testing

X-37:

- Independent Annual Review (IAR) conducted Jan. 25-26, 2000
 - Flight S/W SRS Release 1.0, Jan, 2000
 - X-40A Risk Assessment conducted Feb. 10-11, 2000
 - Initial Design Review (IDR) conducted Mar. 7-8, 2000
 - Fuselage Master Tooling Fabrication Complete April, 2000
- Other Flight Experiments:**
- Composite LOX Tank nearing fabrication completion
 - SHARP -B2 successfully launched on Sept. 28, 2000



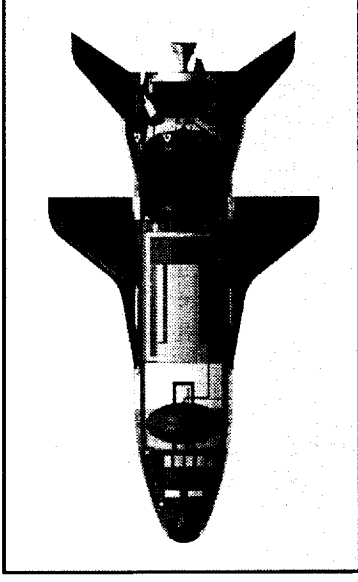
X-34 Vehicle (A-1A) at Dryden



X-37 WTT at LaRC

■ Flight Demonstrator Vehicles

- X-34 Rocket Plane - Mach 8 technology testbed
- X-37 Space Plane - Orbital technology testbed



■ Flight Experiments

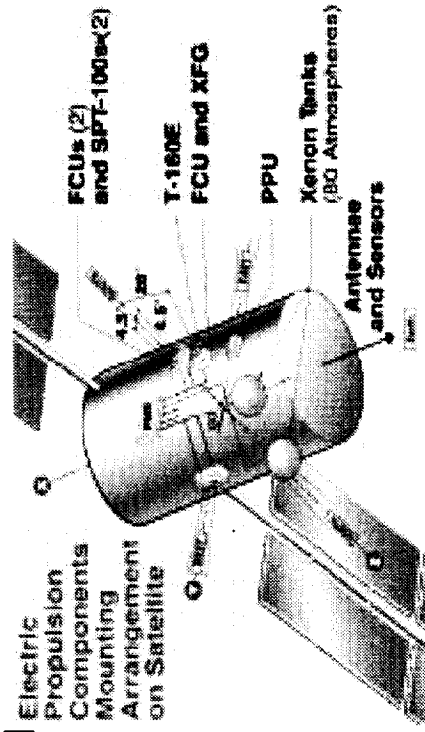
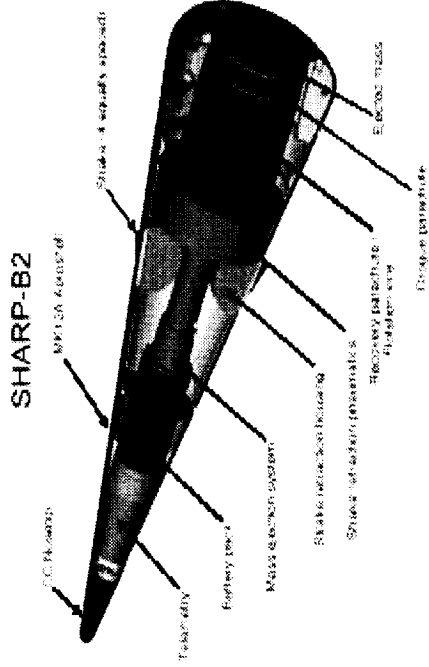
- Flown on X-34:
 - ◆ **GAMMA-TITANIUM ALUMINIUM-BASED TPS (ALENIA AEROSPACE)**
 - ◆ **ADVANCED C/SIC TPS (ESA-DAIMLER-BENZ)**
 - ◆ **MECHANICALLY ATTACHED FLEXIBLE TPS (BOEING)**
 - ◆ **ENCAPSULATED WATERPROOF 2500F CMC TPS (MDA [Now BOEING])**
 - ◆ **FLIGHT TEST DETAILED SPECIMENS IN CERTIFIED HOLDER (MDA [Now BOEING])**
 - ◆ **ACTIVE DAMAGE INTERROGATION HEALTH MONITORING SYSTEM (MDA [Now BOEING])**
 - ◆ **ACOUSTIC EMISSION HEALTH MONITORING SYSTEM (BOEING)**
 - ◆ **AUTONOMOUS ABORT LANDINGS (DRAPER LAB)**
 - ◆ **INTEGRATED VEHICLE HEALTH MANAGEMENT (IVHM) (NASA AMES)**
 - ◆ **COMPOSITE LOX TANK (LOCKHEED-MARTIN)**

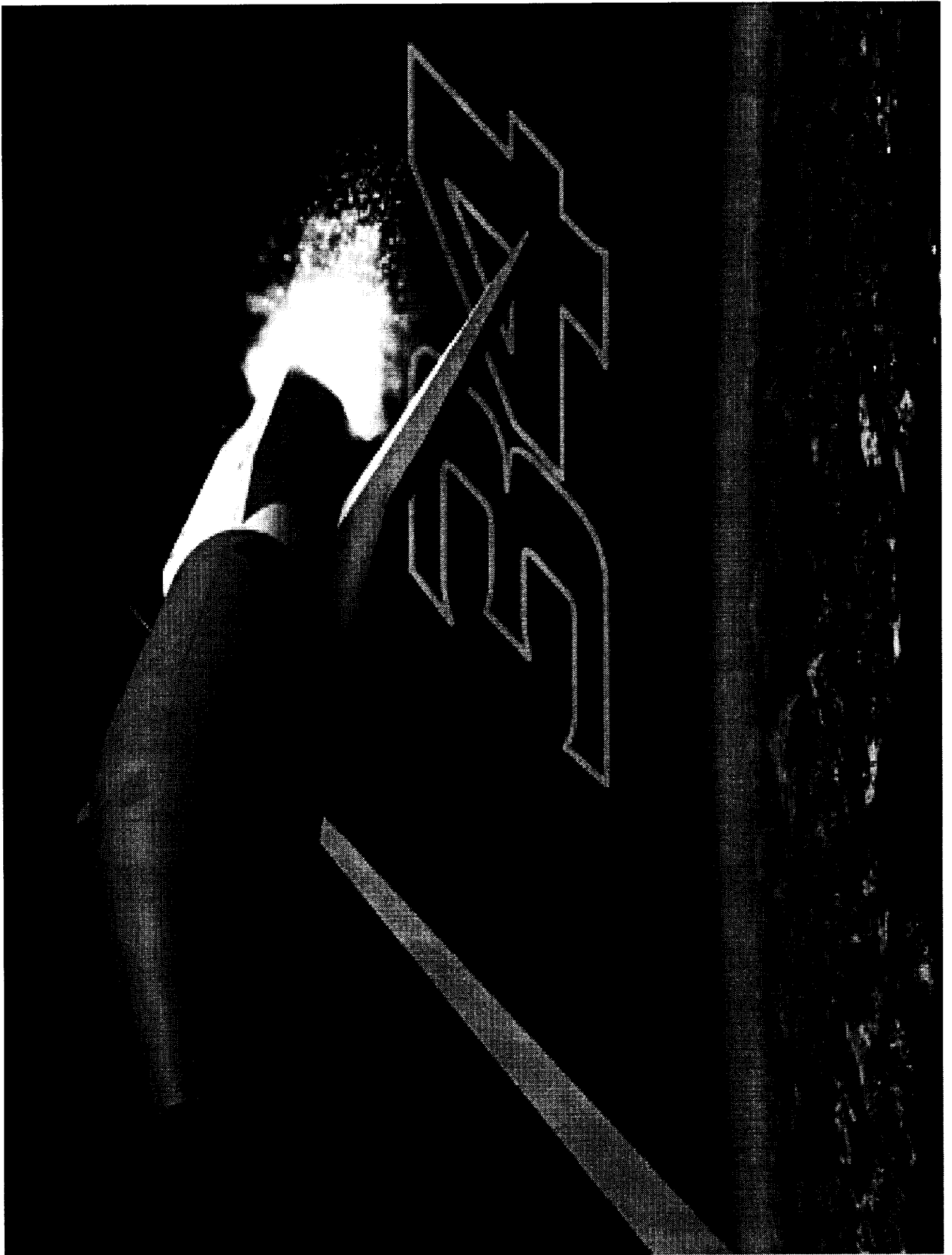


- 40 Embedded or Carry-On Experiments Baseline for X-37

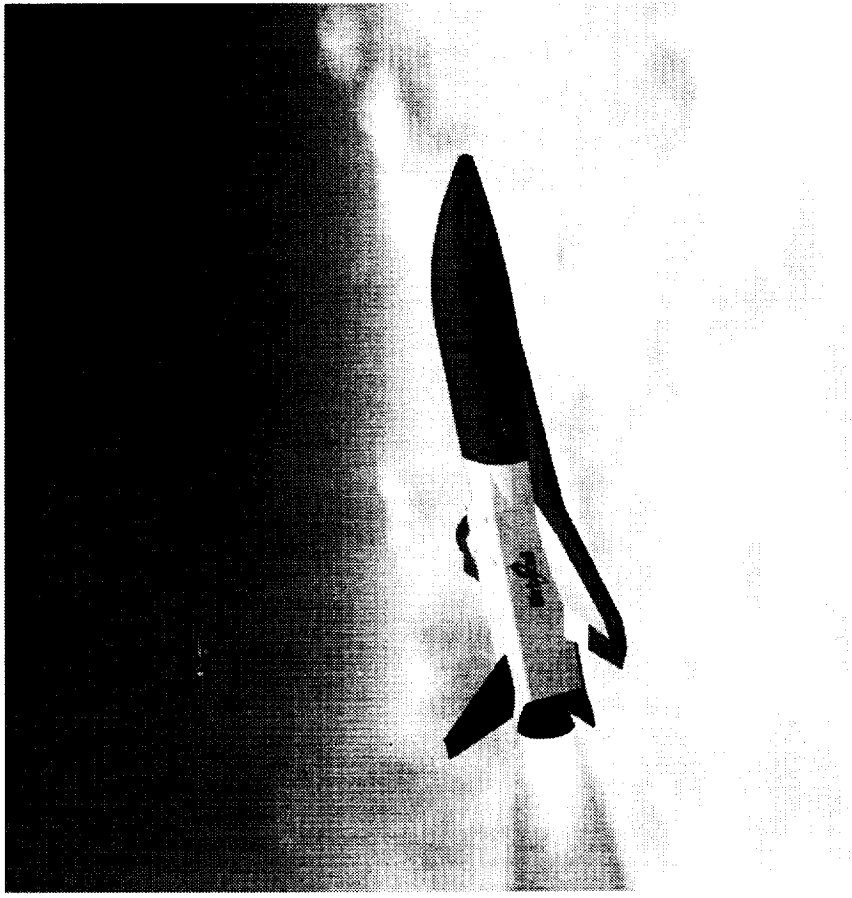
■ Flight Experiments

- Other Flight Experiments:
 - ◆ **REDUCED COST SMALL PAYLOAD TECHNOLOGIES (AERO-ASTRO)**
 - Deployed from the Space Shuttle
 - ◆ **CERAMICS FOR SHARP LEADING EDGES (NASA AMES)**
 - Flown on a Minuteman III
 - Successfully launched on Sept. 28, 2000
 - ◆ **ProSEDS (NASA MSFC)**
 - Flown as a secondary payload on a Delta II upper stage
 - ◆ **HALL EFFECT THRUSTER (NASA GRC)**
 - Instrumentation flown on a Russian communications satellite
 - ◆ **CRYOGENIC PROPELLANT GAUGE (NASA GRC)**
 - Flown on the USAF Solar Orbit Transfer Vehicle Space Experiment





- **RLV Goal: to Significantly Reduce the Cost of Access to Space**
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New RLV Technologies Embedded in Vehicle Design

- **Demonstrate technologies throughout flight profile**
 - Subsonic and hypersonic flight
 - Capable of powered flight to at least 250 K ft
 - Capable of attaining Mach 8
- **Capable of autonomous flight operations**

Investigation of New Methods for Low-Cost Operations

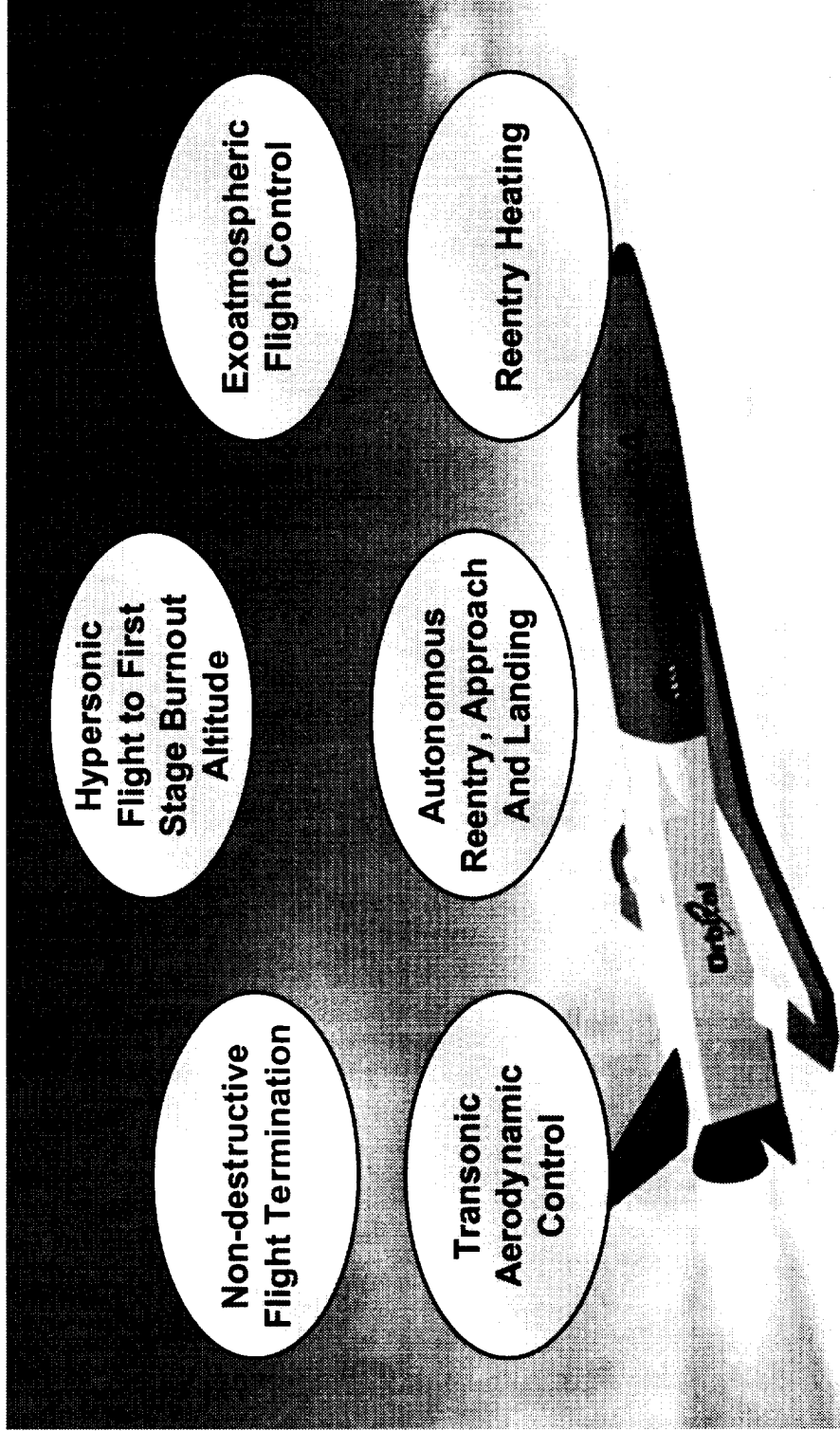
- **Capable of demonstrating safe abort**
- **Capable of 25 test flights over a period of one year (OMB metric)**
- **Low cost operations**
 - Small work force
 - Nominal 2-week turn-around
 - Surge capability of 2 flights within 24 hours
 - Capable of attaining average recurring flight cost of \$500K
- **Operation in RLV-type environments**
 - Flights through inclement weather
 - Landings with cross winds of 20 knots or greater

Testbed for Hosted RLV and Hypersonic Experiments

- **On-board instrumentation for testing embedded technologies**
- **Small area for “carry-on” experiments**



Flight Testing for a Multistage Reusable System

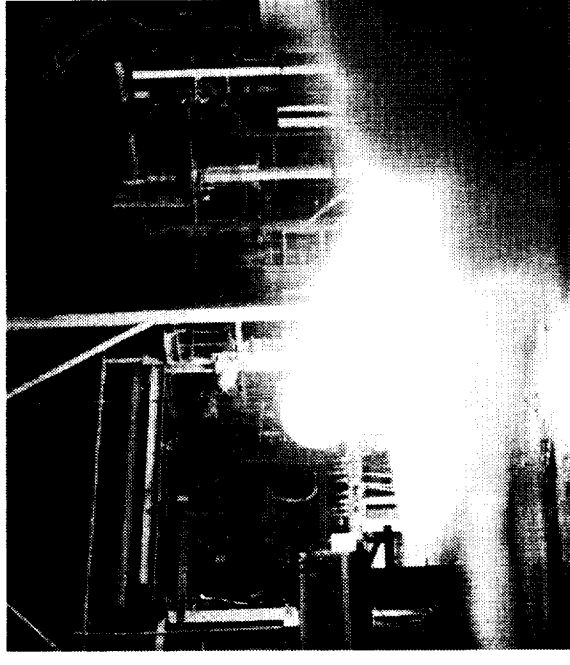
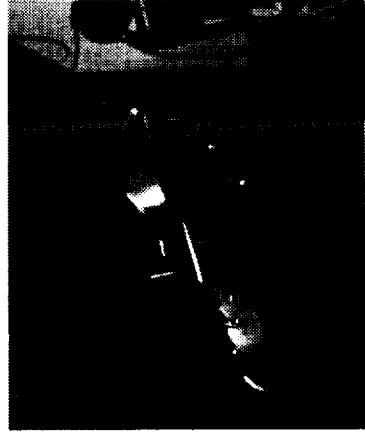


The X-34 Flight Regime Duplicates the Environment and Mission Characteristics Of a Reusable First Stage

Key Embedded Technologies

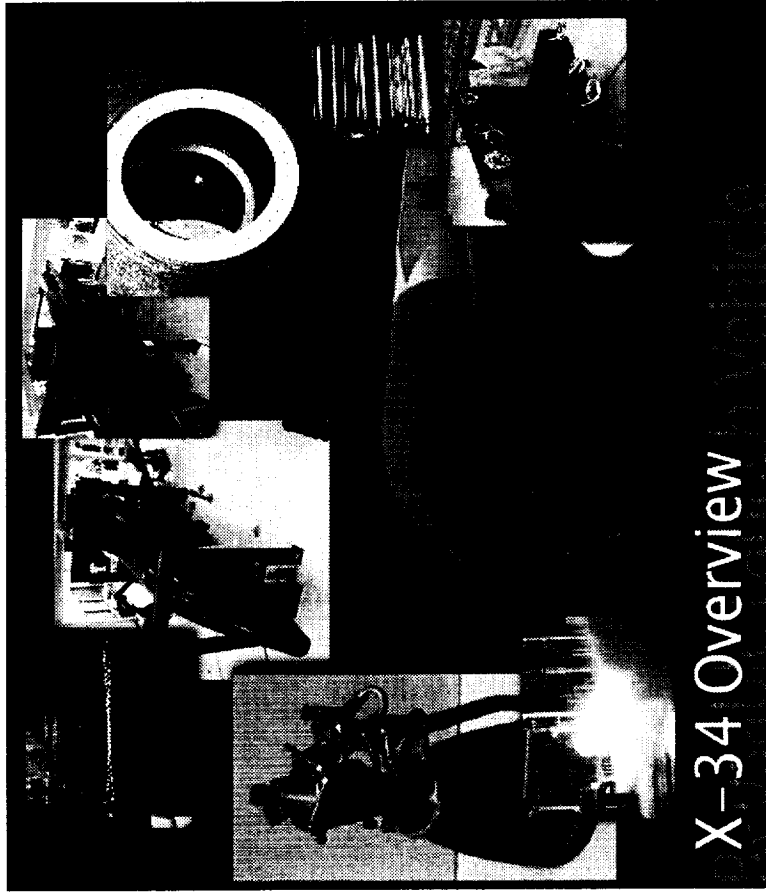


- **Composite Primary and Secondary Airframe Structures**
- **Composite Reusable Propellant Tanks**
- **Integrated Vehicle Health Monitoring System**
- **Advanced Operable TPS Including Leading Edge Materials**
- **Low-Cost Avionics Including Integrated (GPS/INS) and Differential (DGPS) GPS**
- **New Low-Cost Rocket Engine (Government Developed)**
- **Integral Closed Loop Flush Air Data System**

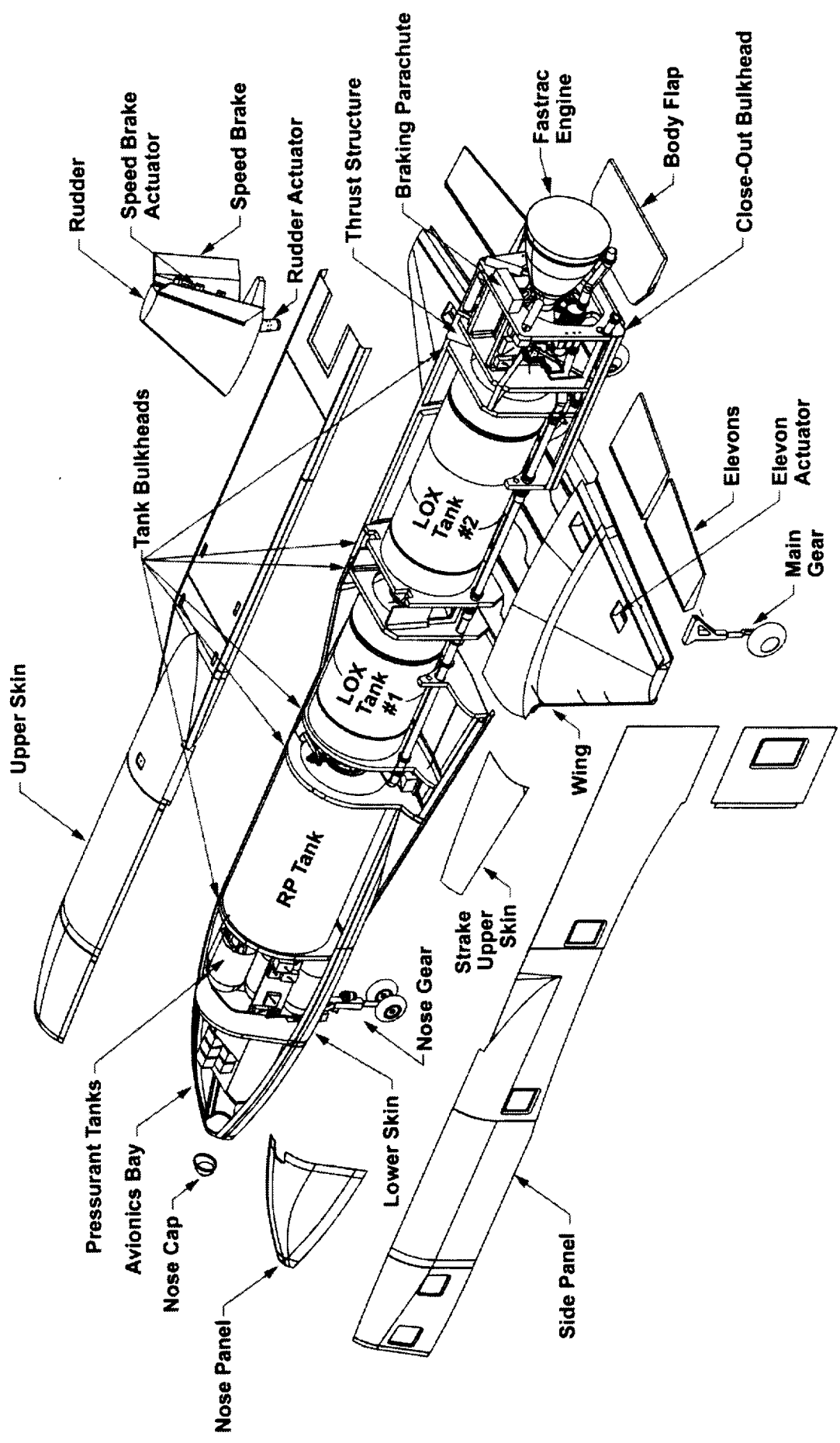


X-34 Vehicle Description

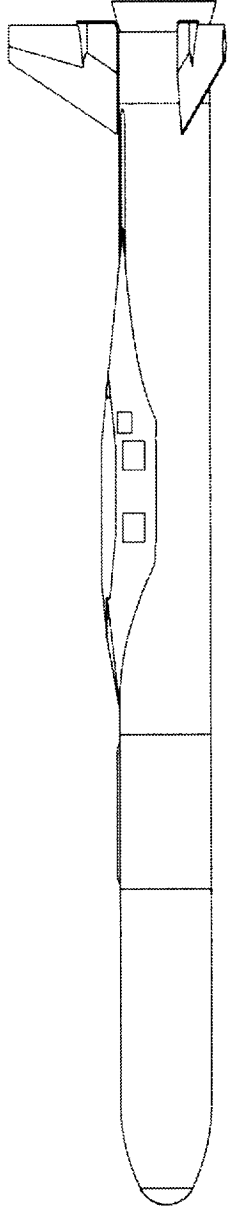
- **Single Stage, Sub-Orbital, Fully Reusable, Unmanned Testbed Aerospace Plane**
- **Three airframes: A-1A, A-2, A-3**
 - A-1A is unpowered, A-2 and A-3 are powered
- **Vehicle Characteristics**
 - Length 58.3ft
 - Wing Span 27.7 ft
 - Gross Weight *45,488 lbs.
 - Propellant *30,350 lbs.
 - Payload 450 lbs.
 - Operating Weight Empty* 15,138 lbs.
 - *Target Weight
- **Airframe**
 - Composite structure and skin
 - One piece wing with center carry through structure
 - Elevation control surfaces
 - All-flying vertical tail
 - Body flap for pitch axis trim
- **Avionics**
 - Single string with exception of dual string flight termination system



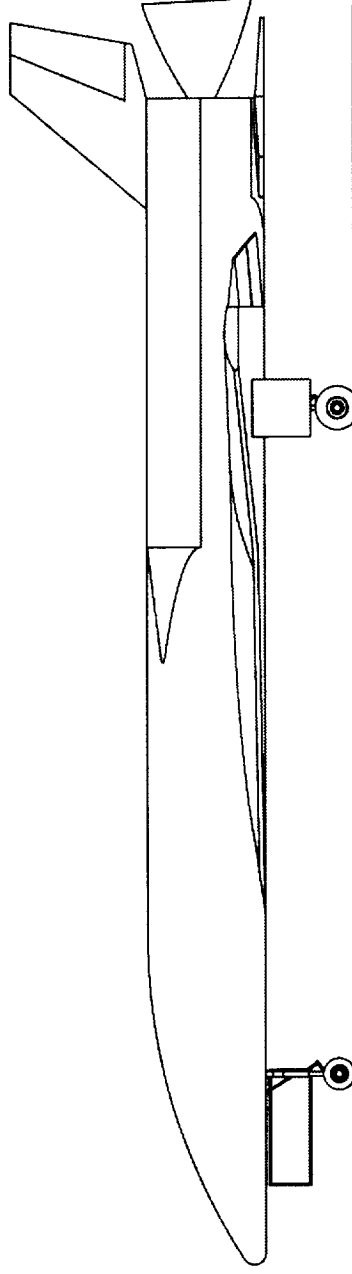
X-34 Expanded View



Vehicle Size Comparison

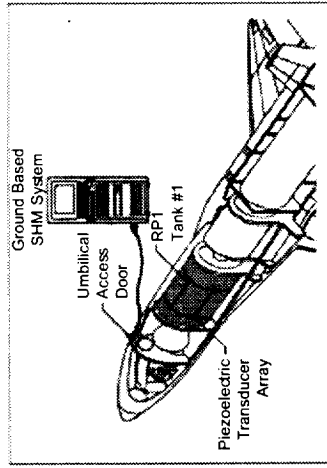


Pegasus XL

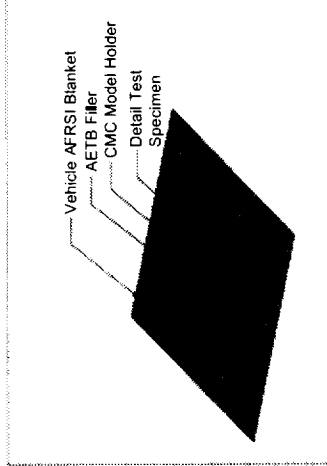


X-34 Technology Testbed Vehicle

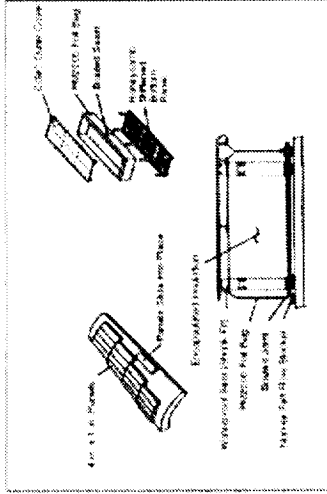
X-34 Experiment Examples



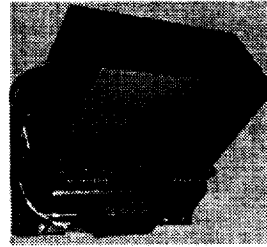
Integrated Structural Health Monitoring System for the X-34 RP1 Tank (Boeing, St. Louis).



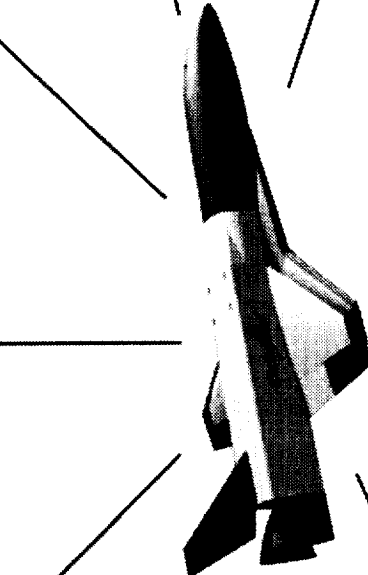
Detail Test Specimen Model Holder (Boeing, Huntington Beach).



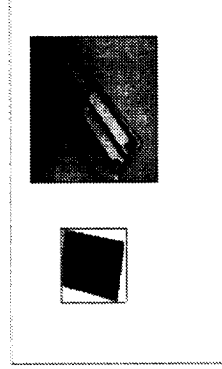
CMC Encapsulated TPS Assembly (Boeing, Huntington Beach).



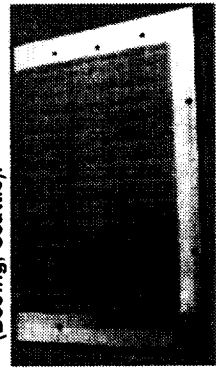
Acoustic Emission Health Monitoring System (Boeing, Seattle).



IFI Blanket TIAI Based TPS (Alenia, Italy)

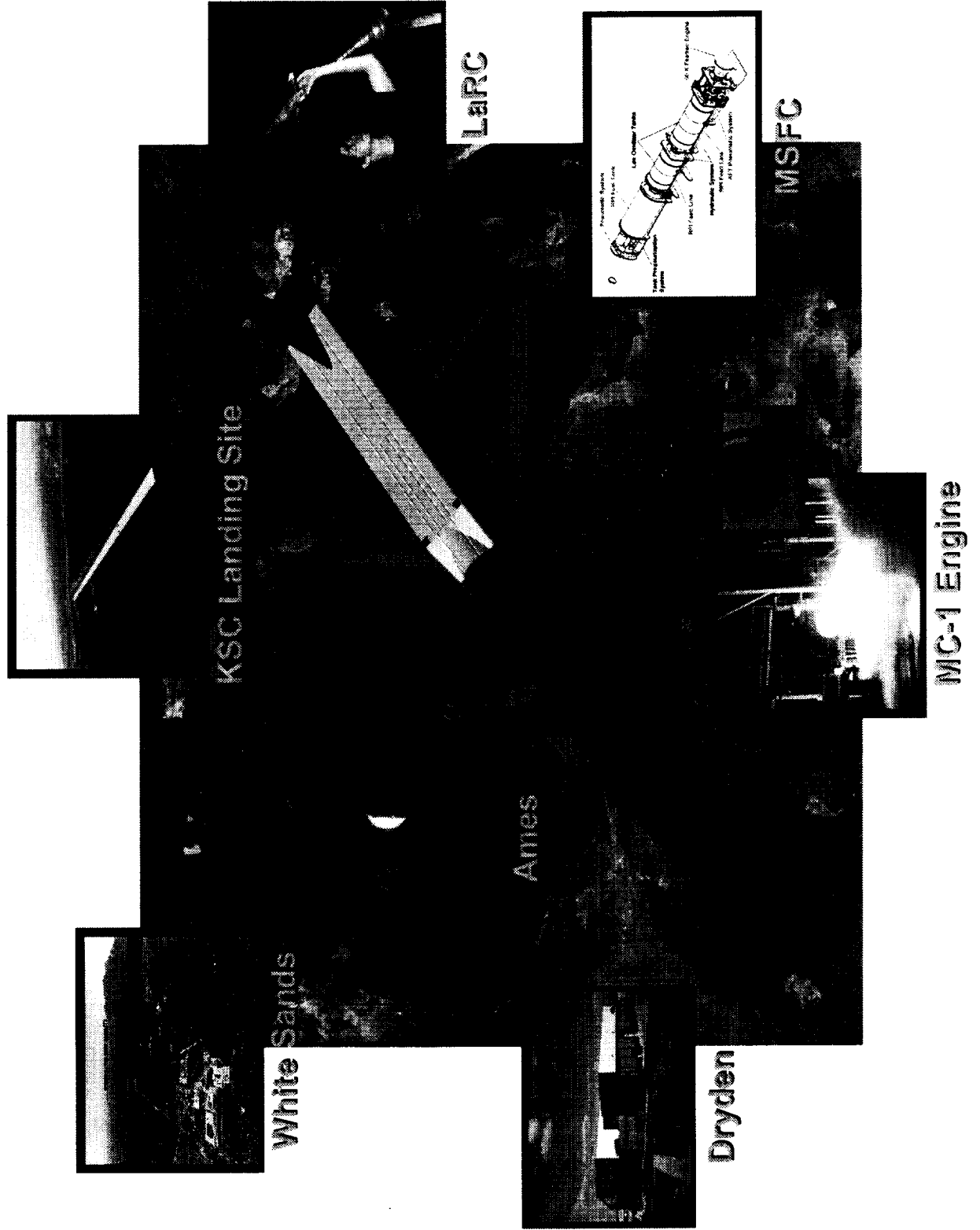


Advanced C/SiC Based TPS (Daimler Benz, Germany).



Mechanically Attached Thermal Protection System (Boeing, Seattle).

Government Participation

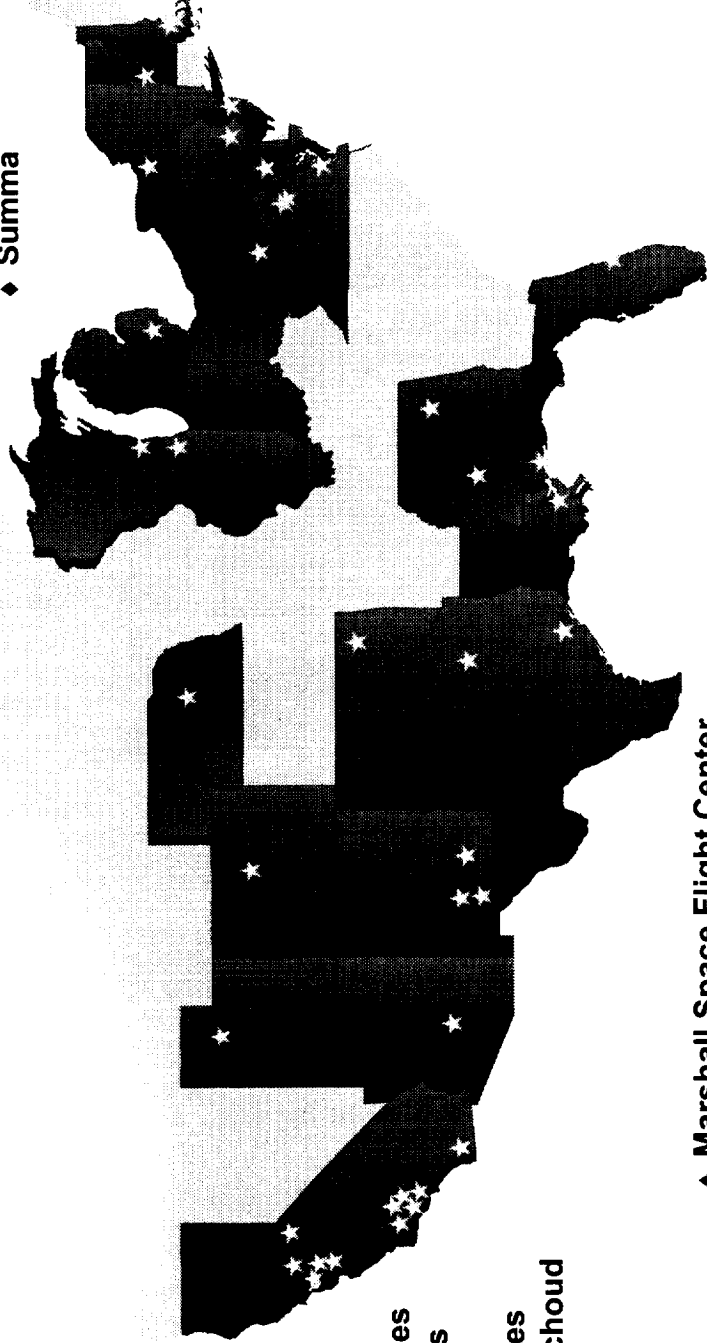


Government and Industry Participants



- ◆ AlliedSignal Aerospace
- ◆ The C. S. Draper Labs
- ◆ Oceanering Space Systems
- ◆ Vermont Composites

- ◆ Litton
- ◆ OR Computers
- ◆ AP Precision Hydraulics
- ◆ Summa



- ◆ Aurora Flight Sciences
- ◆ R-Cubed Composites
- ◆ Spincraft
- ◆ Advanced Composites
- ◆ Lockheed Martin-Michoud

- ◆ Marshall Space Flight Center
- ◆ Ames Research Center
- ◆ Langley Research Center
- ◆ Dryden Flight Research Center
- ◆ Johnson Space Center
- ◆ Holloman Air Force Base

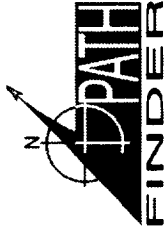
- ◆ White Sands Test Facility
- ◆ Edwards AFB
- ◆ White Sands Missile Range
- ◆ Kennedy Space Center
- ◆ Stennis Space Center



X-34 Restructure Status



- **A-1A complete at DFRC, A-2 complete at Orbital, A-3 fuselage structure complete at Orbital**
- **A-1A tow testing to begin at Edwards AFB week of May 15th**
- **Two reviews completed; others planned for the near term**
 - Sackheim propulsion system review
 - McConnaughey avionics and flight controls review
- **A-1A has been judged ok for unpowered drop tests at White Sands Space Harbor, starting in early '01**
 - Consensus of MSFC, DFRC, Orbital, and the McConnaughey review team
 - Assumes addition of increased hardware-in-the-loop testing, surrogate aircraft flights, and minor hardware fixes
- **Significant work required before A-2 is ready for first powered flight in '02**
 - Will add integrated vehicle/engine testing (e.g., MPTA), a key Sackheim team finding
 - RPV link will be added to allow some level of human control of the vehicle during contingencies
 - Avionics will be upgraded with the goal of "no single failure results in loss of vehicle"
- **Program is working closely with Second Generation Program to ensure synergy, including use of A-3**
- **A new contract arrangement will be established with Orbital**
- **New program leadership at MSFC and Orbital**
- **DFRC role in X-34 will be significantly increased; e.g., DFRC will provide Deputy Program Manager**



Significant Events/Accomplishments

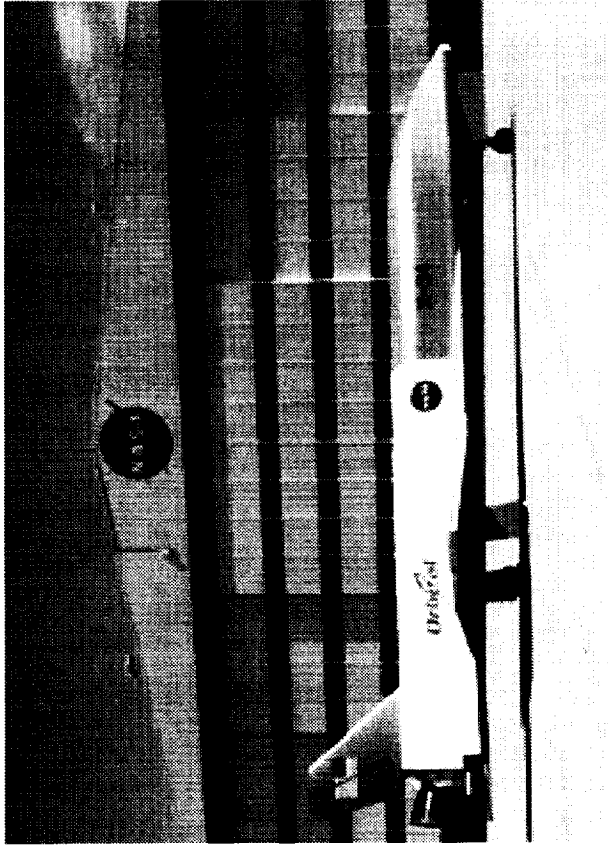


- Shipment of A-1 Vehicle to DFRC
- SVR (System Verification Review) at OSC
- Roll Out of A-1 Vehicle at DFRC
- Installation of LOX & RP Tank into A-2 Vehicle
- Completed a project sparing study and received a proposal for long lead spares
- GVT (Ground Vibration Test) of A-1 Vehicle with L-1011
- Initiated Captive Carry Flight Testing with the X-34 and L-1011
- Received final direction on range operations: [unpowered flights at WSMR, powered flights at Dryden & KSC]
 - Proposal received from OSC and is in review
- Incorporated additional risk mitigation activities such as IV&V of software, Tow Testing, and conversion of A-1 to unpowered flight status
- Delivered 2nd flight wing to OSC
- Completion and Integration of Wing #2 with the A-2 Fuselage
- Conducted Independent Code Q Review
- Defined requirements for the 3rd party indemnification of X-34 by NASA
- Defined and initiated environmental work to support flights as defined within the project
- Defined and negotiated three new experiments to fly on X-34 (Robust abort, Composite Lox Tank, & IVHM)
- Put in place new contract with Summa to provide engines and support for the 25 flight option
- Completed the retrofit of A-1 to A-1A with the combination of DFRC, KSC, MSFC, and OSC manpower (system testing underway)

X-34 Project Status



- **Restructuring effort underway**
 - Possible increase in ground testing for engine and vehicle, avionics mods, and new propulsion test article
 - Focused to support 2nd Gen Program
- **A-1A unpowered vehicle complete and on the runway at Edwards AFB**
 - Series of captive-carry flights and high-speed tow tests underway
- **A-2 powered vehicle complete and undergoing tests at Orbital's Dulles facility**
- **A-3 airframe essentially complete at Orbital's Dulles facility**
- **MC-1 (formally Fastrac) engine testing continuing at Rocketdyne's SSFL in Calif.**
 - 45 hot-fire tests already completed at SSC



Project Status

Last Month's Accomplishments

- **Significant Progress achieved on updating the X-34 Contract**
 - Majority of Task Directives closed or suspended
 - ◆ **Tow test TD open until September 1st**
 - ◆ **Mission Success Support TD and IV&V TD will remain open**
 - ◆ **All other TDs terminated or suspended**
 - Paid Orbital \$4.4M in provisional Milestone Payments for partial completion of Milestones
 - 1 open Request for Equitable Adjustment (REA) value \$1.1M
 - 1 Open Contract Mod (Mod 32)
 - ◆ **Plan to negotiate by September 31**
 - ◆ **NTE Period of Performance extended to allow work to continue**
- **Conducted tow tests of A-1A vehicle on DFRC lakebed**
 - 4 tests successfully conducted, including a 30 mph release test
 - Test anomaly occurred on 1st & 6th test
 - ◆ **Only damage to vehicle was Nose gear tire**
 - ◆ **NG tires have been replaced.**
- **Worked with TD management on restructure trades/options**
- **Supported Internal ISO 9000 Audit**
- **Continued the build of the first powered flight vehicle (A-2)**

Project Status

Last Month's Accomplishments (continued)

- Supported Osh Kosh Airshow with flight engine display
- Proof load tested Engine Installer
 - Problems identified with anti rotation mechanism
 - Retest next month
- Conducted turbopump water flow tests
- Supported range safety requirements review and assessment
 - Current design of Engine MOV & GGOV will not likely be able to comply with rqmnts

■ Conducted engine tests at Santa Susana facility in CA

Date	Planned Dur (sec)	Actual Dur (sec)	Objective
18-Jul	5	5	Start Sequence
29-Jul	24	24	Calibration Baseline
8-Aug	24	24	LOX inlet Ramp-up
17-Aug	24	24	Calibration Verification

Project Status

Next Month's Plan

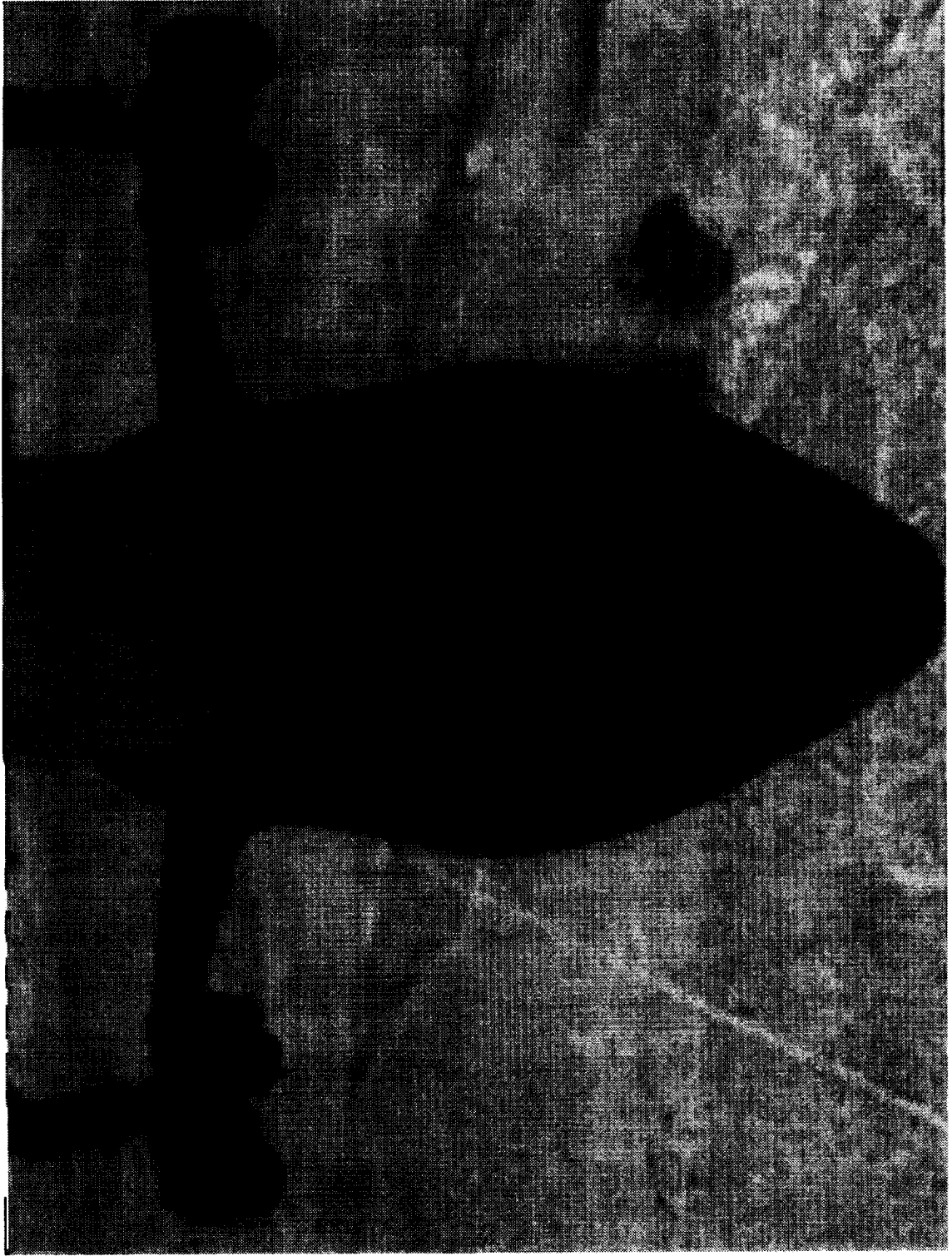
- **MSFC/DFRC site visit to WSMR, WSTF and Holloman AFB - Aug 28-25**
- **Conduct Audit of Orbital actual costs on X-34 - Aug 28-31**
- **Support GAO Review as required**
- **Support IG Audit**
- **Closeout Tow Test Task Directive (9-1-00)**
- **Captive Carry Flight Test Planning**
- **Reconfigure A-1A Vehicle for resumption of FAA Captive Carry tests**
 - **Dependent upon L1011 availability**
- **Increase Project and project support staffing**
- **Develop X-34 Systems Requirements Document**
- **Baseline X-34 Configuration Management Plan**
- **Develop FY01 CWCs**
- **Develop Detailed schedule and cost plan for unpowered flights & A-2 integrated propulsion testing**
 - **Powered flight portion of the project dependent upon funding and Management decisions**

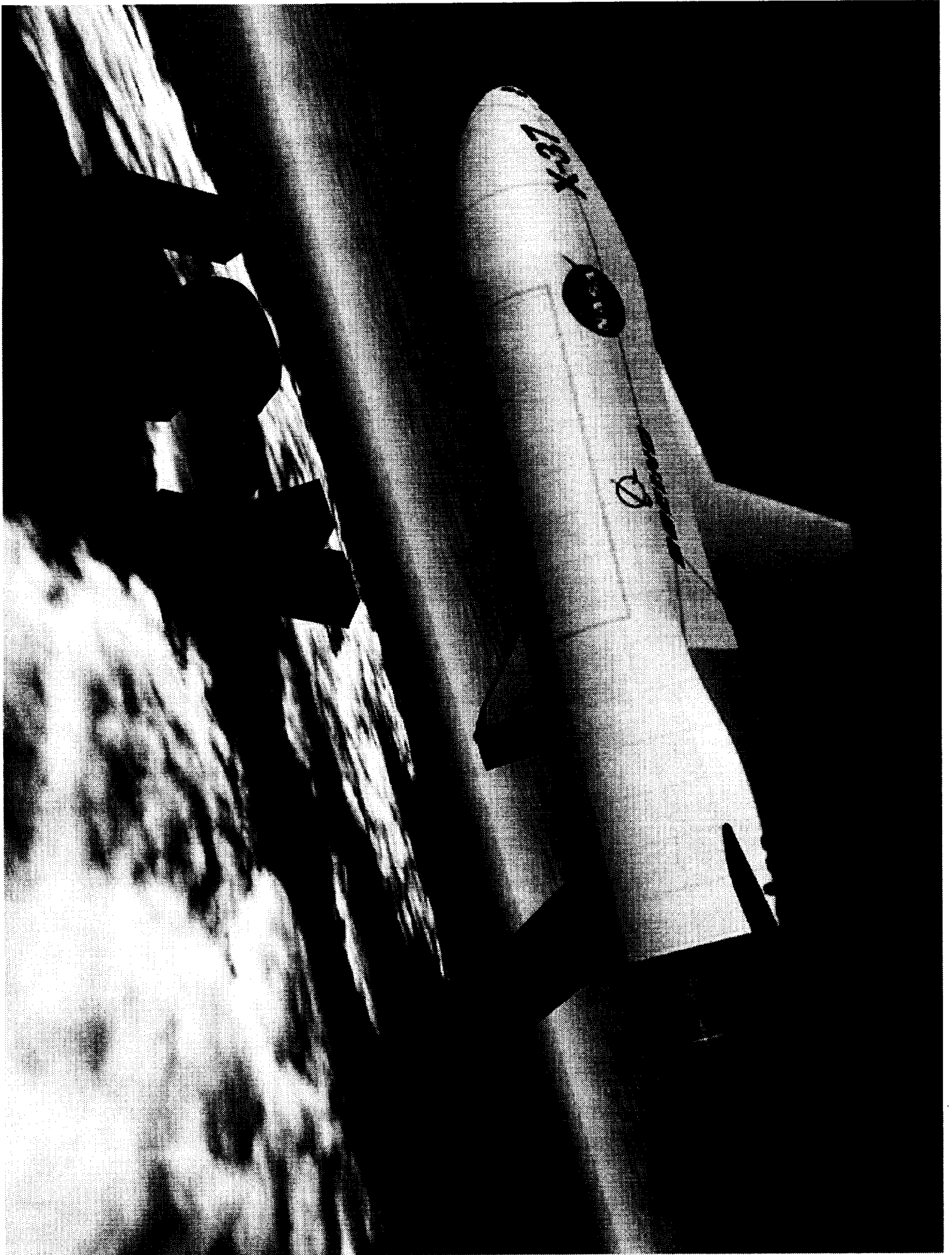
Project Status

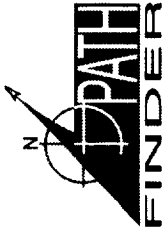
Next Month's Plan (continued)

- **Continue discussions with Range safety at DFRC on FTS requirements**
- **Continue working partnership agreements with DFRC**
- **Finalize Tip to tail Review SOW and negotiate change with Orbital**
- **Continue to work with TD Management on restructure planning & trades**
- **Complete the integration of flight vehicle A-2**
 - Main propulsion system
 - Avionics system
- **Begin IV&V stress testing of flight software**
- **Continue Engine Testing at SSFL**
 - Engine #3 full duration test (159 sec)
 - Engine #5 calibration test(s)
- **Retest engine installer (proof load test)**
- **Conduct engine #4 installation and fit check in A-2 vehicle at Dulles**

X-34 Captive Carry Flight







X-37 Project Objectives



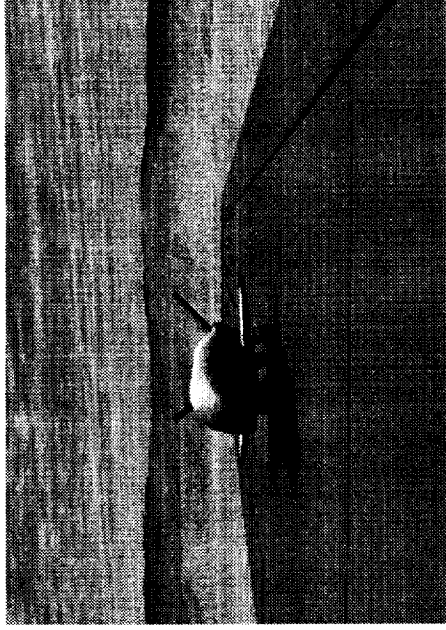
- ◆ **Mature the technologies for reusable space vehicles by performing flight demonstrations.**
 - ◆ Lower the cost for routine access to space and operations in space.
 - ◆ Make next-generation space transportation system commercially viable.
 - ◆ Enhance planning for future reusable launch vehicle space operations.
- ◆ **Enable investor confidence in reusable space vehicle systems.**
- ◆ **Achieve a technology readiness level of 8 (flight proven) for critical technologies.**
- ◆ **Design and operate with an emphasis on safety.**

Successfully Achieve Orbit and Return to Earth Safety

X-37 Project Specifics



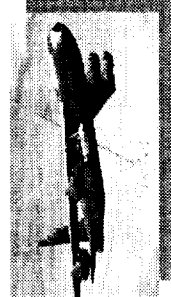
- ◆ **Project Objective**
 - Demonstrate technologies required to reduce the cost of access to, in, and from space
- ◆ **Key Features**
 - Designed to close current X-Vehicle capabilities gap
 - Addresses both Earth-to-Orbit, Orbit-to-Orbit, and Reentry technologies in single testbed vehicle
 - Modularized for rapid insertion of broad range of technologies and experiments
 - Flight test program follows progressive envelope expansion -- potential launch platforms include:
 - B-52, Shuttle, ELV

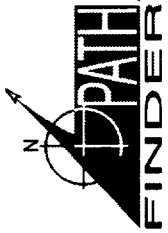


Fuselage Length (ft)	25.7
Wing Span (ft)	14.4
Payload (lb)	500
Entry Weight (lb)	5,800
GLOW (lb)	13,090

◆ Program

- First Flight: Mid 2003 on Shuttle
- Two orbital flights planned





X-37 Funding



\$16M

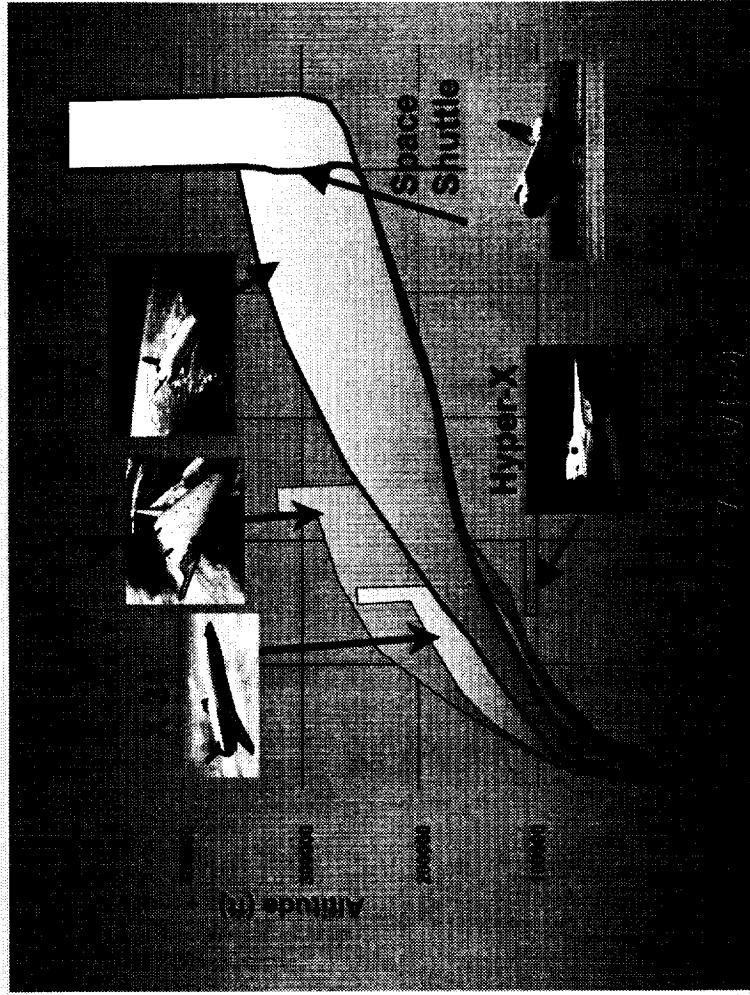


\$72M

\$85M

Successfully Achieve Orbit and Return to Earth Safely

X-37 Tests RLV Flight Envelope



X-34

atmospheric flights
up to Mach 8.

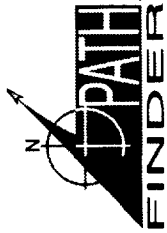
◆ **Hyper-X**
atmospheric flights
up to Mach 10.

X-33

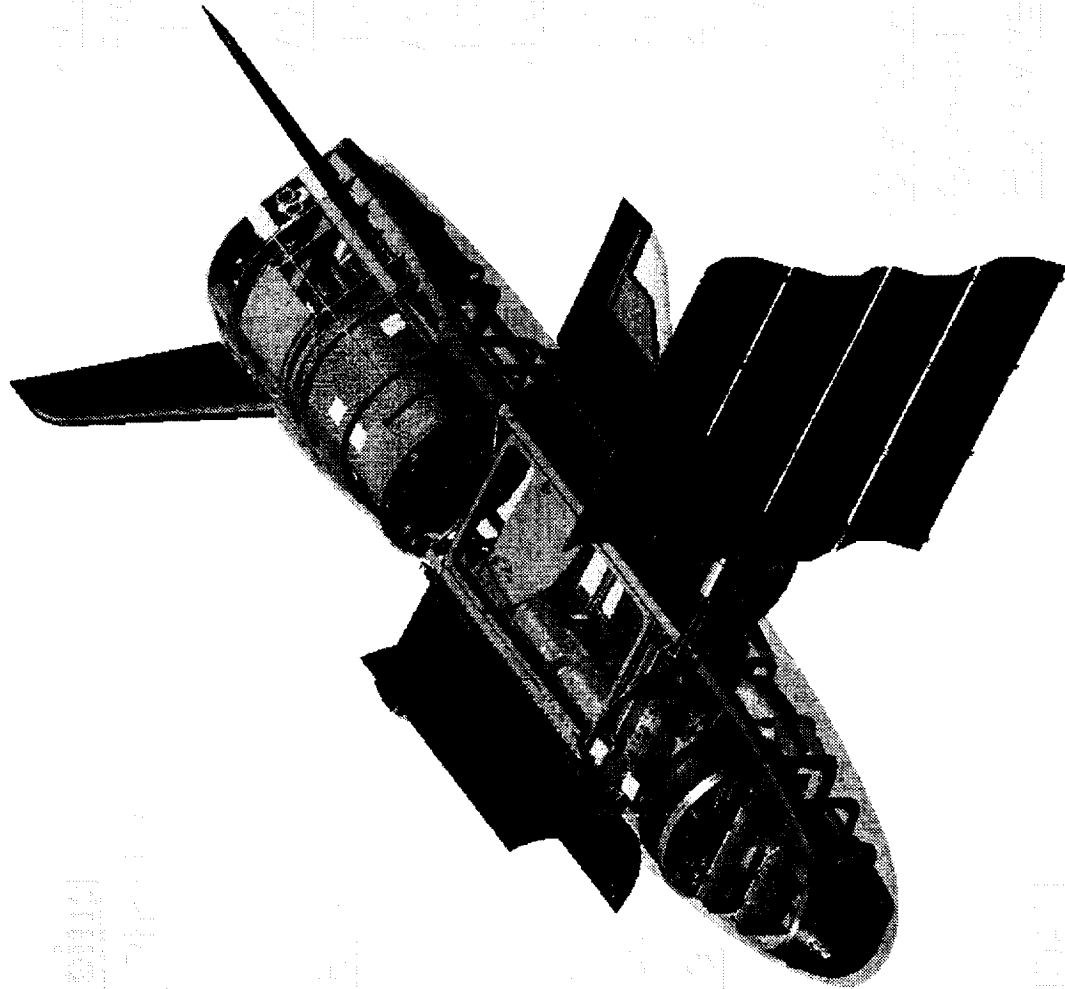
atmospheric flights
up to Mach 12.

X-37

Successfully Achieve Orbit and Return to Earth Safely



X-37 Industry - Government Team



Boeing

Deel Press: 7/1/01

WuKc

WuKc

Hampton

WuKc

SE LOUIS

WuKc

Long Beach

WuKc

WuKc

WuKc

WuKc

WuKc

WuKc

WuKc

NASA

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X-37 Program Products



X-40A

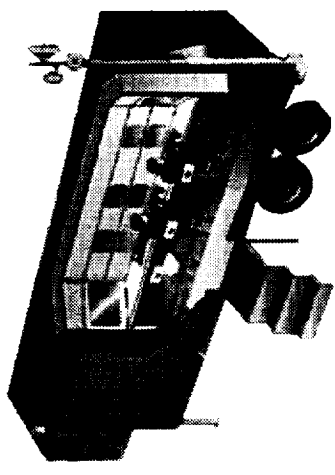


- ◆ Prior USAF Contract: Successful automated approach and landing flight in October 1998.
- ◆ Modified for early atmospheric flights to support X-37 design.

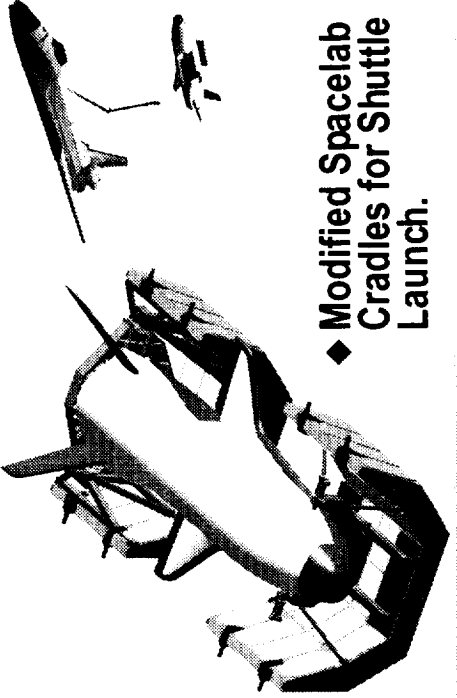
X-37



- ◆ Advanced Technology Flight Demonstration Vehicle.
- ◆ Linked to Space Maneuver Vehicle design.



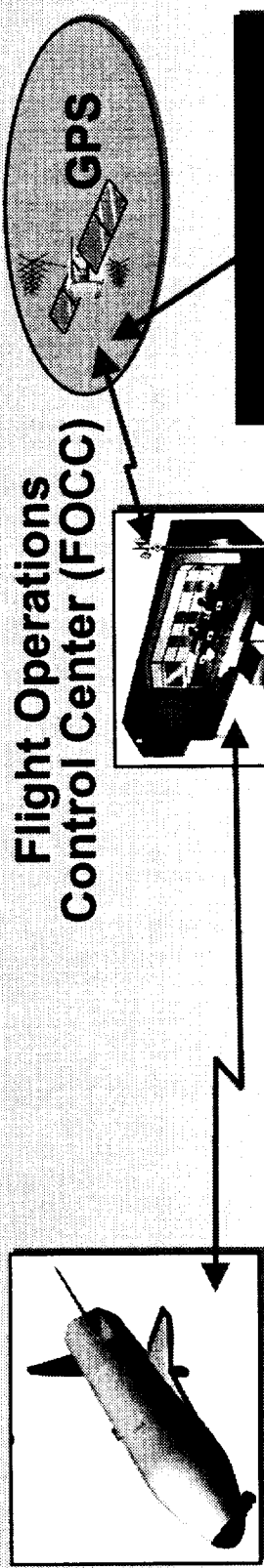
- ◆ Flight Operations Control Center (FOCC).
- ◆ Three person operation for atmospheric and orbital flights.



- ◆ Modified Spacelab Cradles for Shuttle Launch.

Successfully Achieve Orbit and Return to Earth Safely

Overview of X-37 Flight Test Program

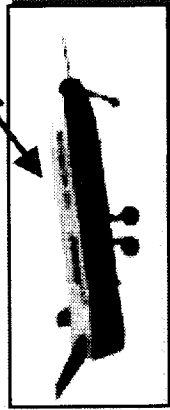


Ground Test/Simulation & Preflight Checkout

Flight Operations Control Center (FOCC)

GPS

X-37/Space Shuttle



X-40A



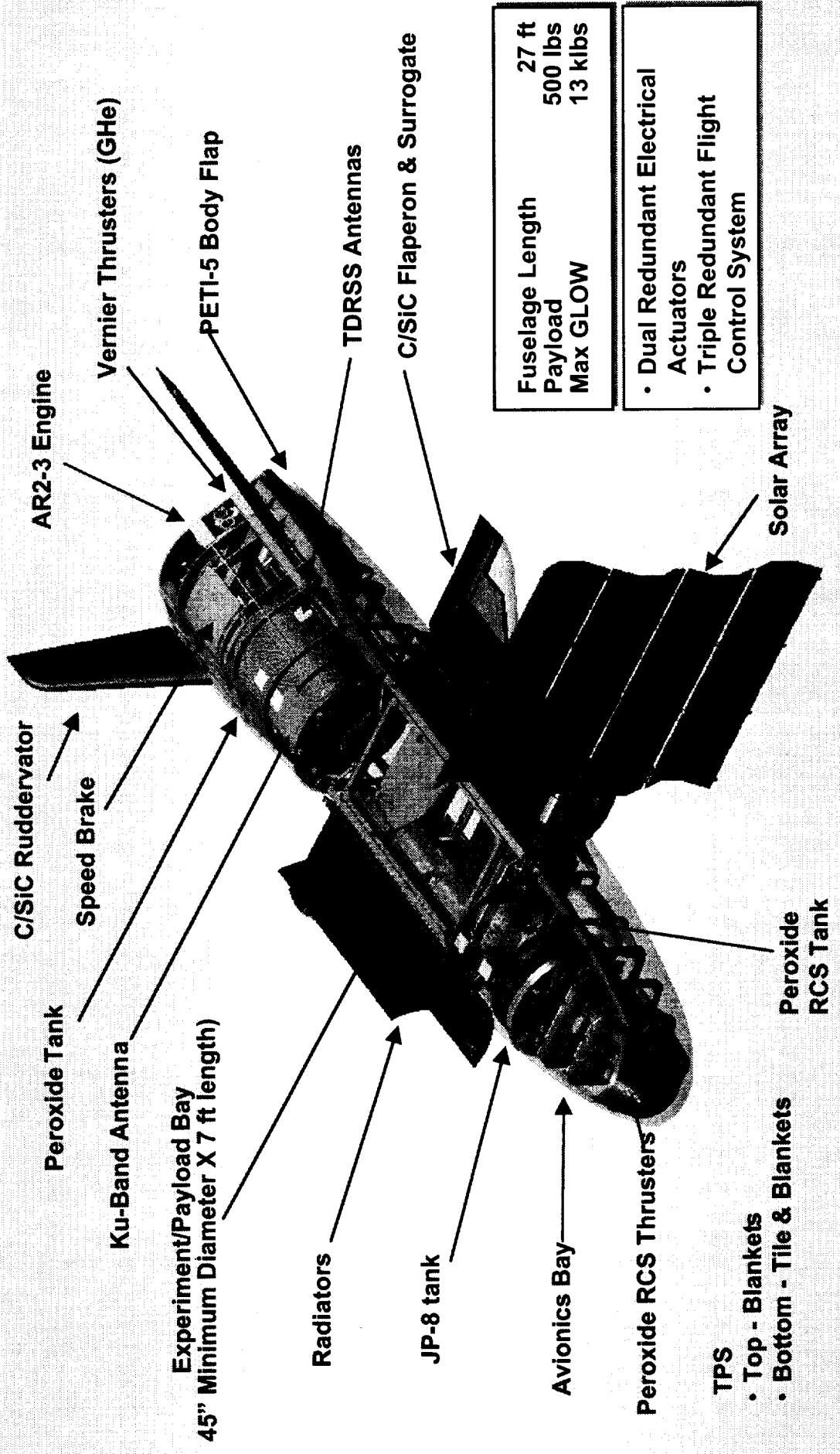
X-37/B-52

Tow/Taxi	5	5
Captive Carry	3	3
Approach and Landing	7	5

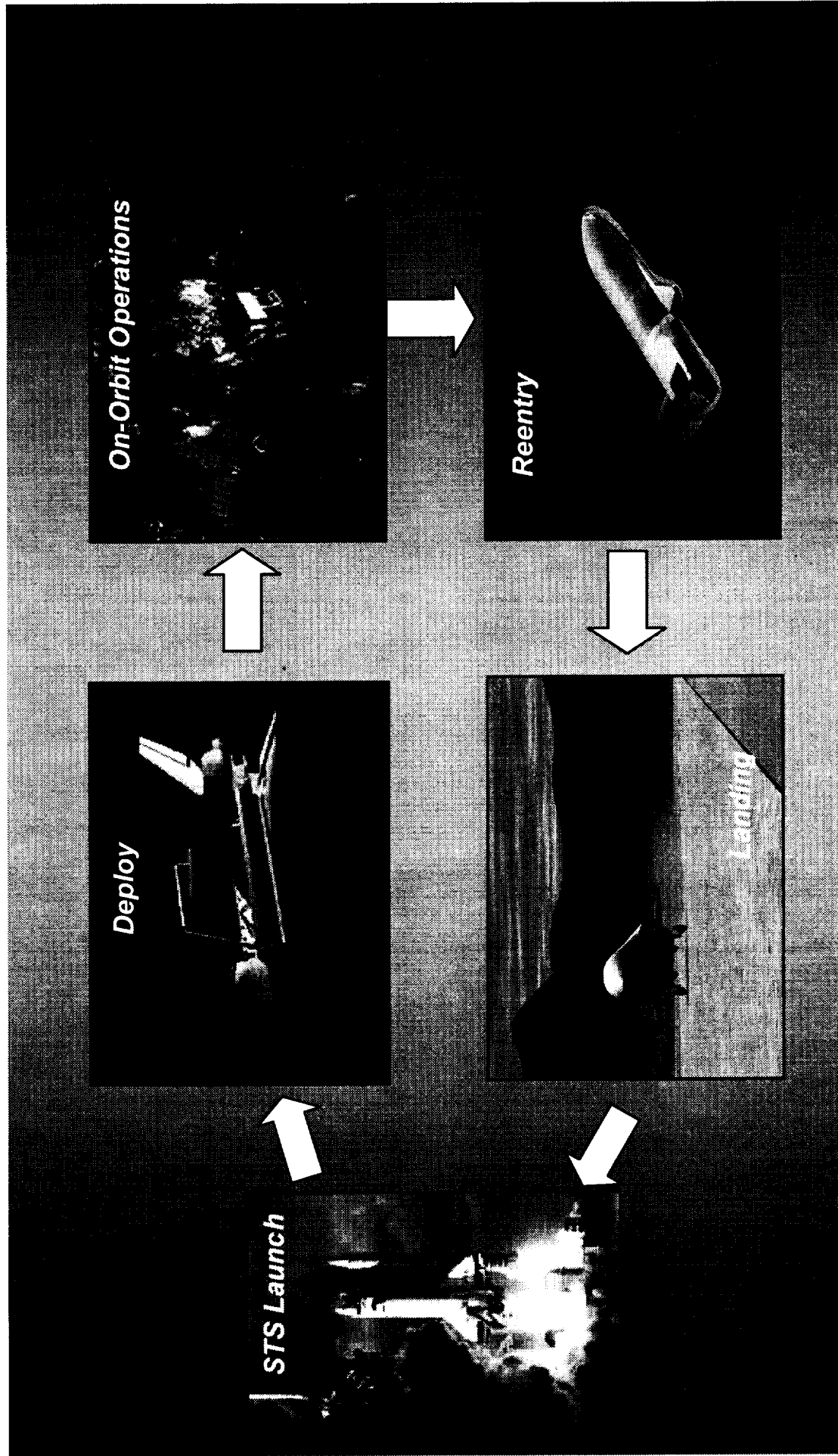
Progressive Ground and Flight Testing In Multiple Environments

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X-37 Vehicle Characteristics

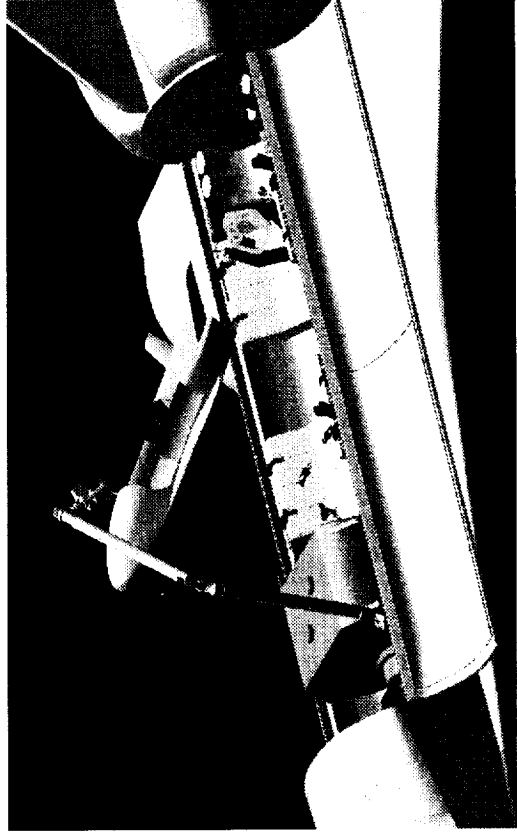
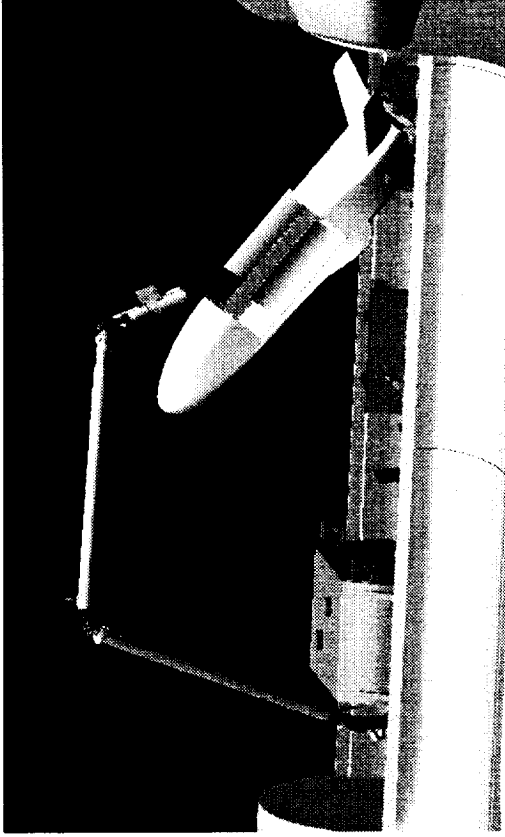


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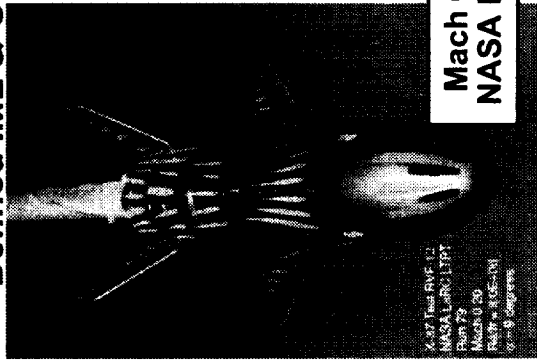
Successfully Achieve Orbit and Return to Earth Safely

X-37 Vehicle Deployment Process

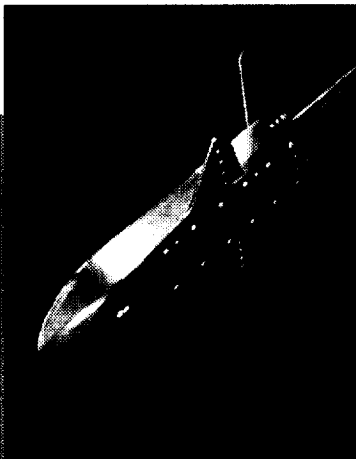


Vehicle Design and Tooling are On Track

Wind Tunnel Testing Has Defined IML & OML



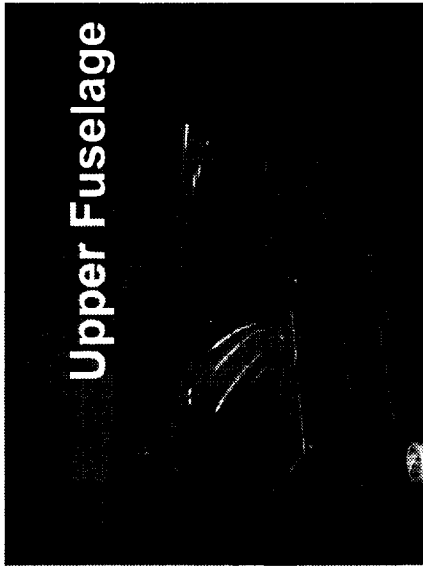
**Mach 0.20
NASA LTPT**



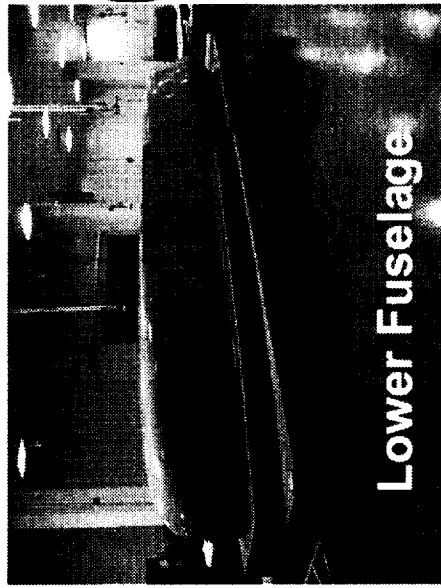
**Mach 0.9 - 5.5
Boeing PSWT**

**Mach 13
AEDC Tunnel 9**

Fuselage Master Tools Complete

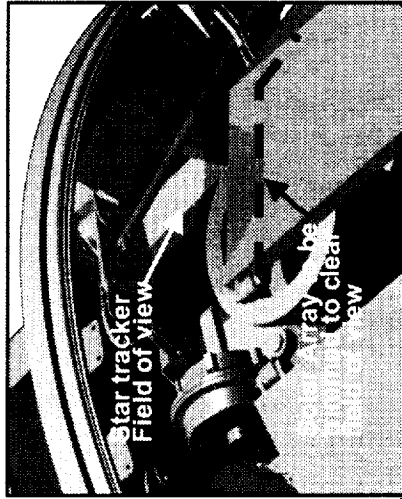


Upper Fuselage



Lower Fuselage

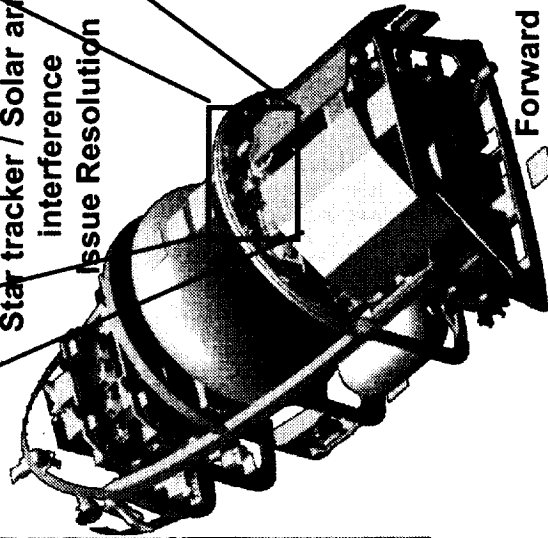
Interior Arrangement is Defined



**Star tracker
Field of View**

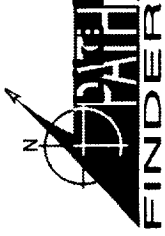
**Solar Array
to be
positioned to clear
Star tracker
Field of View**

**Star tracker / Solar array
interference
Issue Resolution**



Forward Fuselage

Use/disclosure of data contained on this sheet is subject to **Category B** restriction contained in NASA/Boeing Cooperative Agreement NCC8-190, Appendix C to Part 1274, Exhibit B. Date is fully releasable without restriction three (3) years from the date of this document.



Prior X-Vehicles, X-37 Will 1st Develop, Fly, Measure and Discover In Many Important Aerospace Areas



- ◆ **1st autonomous orbital X-plane**
- ◆ **1st development of a re-deployable solar array for a reusable vehicle**
- ◆ **1st use of phase change brakes**
- ◆ **1st extensive re-use of Li-Ion Batteries in aerospace**
- ◆ **1st flight of five TPS types at high enthalpy**
- ◆ **Discoveries in high hypersonic flight environment at lower than Space Shuttle Reynolds numbers**

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Advanced Technologies and Experiments are Being Demonstrated on the X-37



Avionics/Software
 T-12 Open Architecture Avionics
 T-14 Fiber-Optic Data Bus
 T-15 Ku-Band Phased Array Antenna
 T-16 COTS Hardware and Software*
 T-19 Fault Tolerant Autonomous Ops
 T-28 Small Crew FOCC*

Ground/Flight Operations
 T-18 Rapid-Global TPS Damage Detection
 T-21 Rapid TPS Waterproofing

Flight Sciences
 T-22 High Enthalpy Flight Profile

Structures
 T-6 High-Temp Gr/BMI Sandwich Structure
 T-8 Thin, Hot Aerosurfaces for SRSV
 T-11 Modular Airframe - Rapid Change-Out
 T-20 Lt. Wt. Std Payload Container
 T-23 Standard Payload Interfaces
 T-32 High-Temp Gr/PETI-5 Structures
 T-XX Composite Propellant Tanks

GN&C
 T-11 Calculated Air Data System (CADS)*
 T-17 All-Weather Windward Adaptive Guidance
 T-26 Rapid Mission Data Loading*
 T-29 Crosswind Landing for Small RSV's*

Vehicle
 T-23 Standard Payload Interfaces
 T-24 Access Doors for Operability

Mechanical Systems
 T-10 Lightweight Landing Gear
 T-31 Phase Change Brakes

Propulsion
 T-2 Peroxide RCS Thrusters
 T-27 Low Cost Propulsion System

- ◆ Thirty embedded technologies
- ◆ Seventeen advanced vehicle technologies
- ◆ Thirteen advanced operations technologies

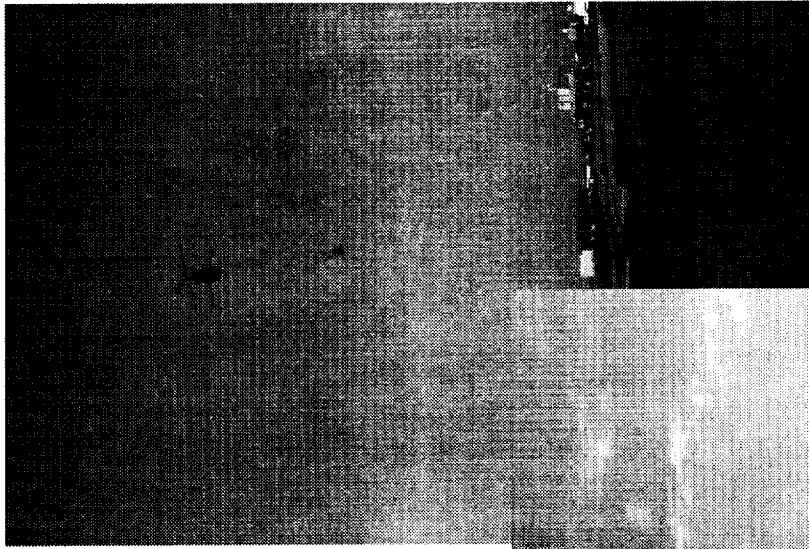
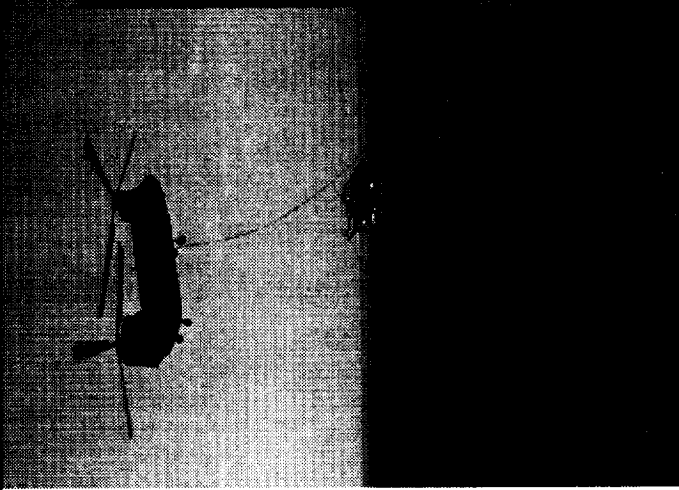
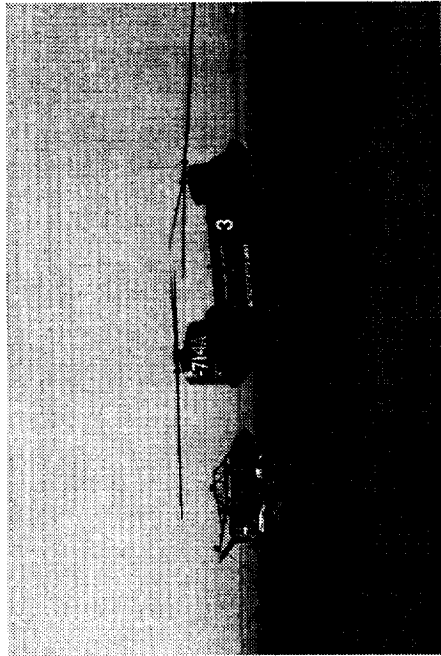
Thermal Systems

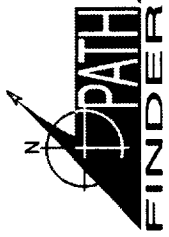
T-3 High-Temp Windward TPS
 T-4 High-Temp Upper/Side TPS
 T-6 Durable Leading Edge Tiles
 T-7 High-Temp, Low Cost Joints/Seals
 T-9 Leap Heat Pipe TCS
 T-14 Failure Resistant
 T-16 Durable, Low Cost
 T-19 Weatherproof Stand
 T-27 Highly Operable

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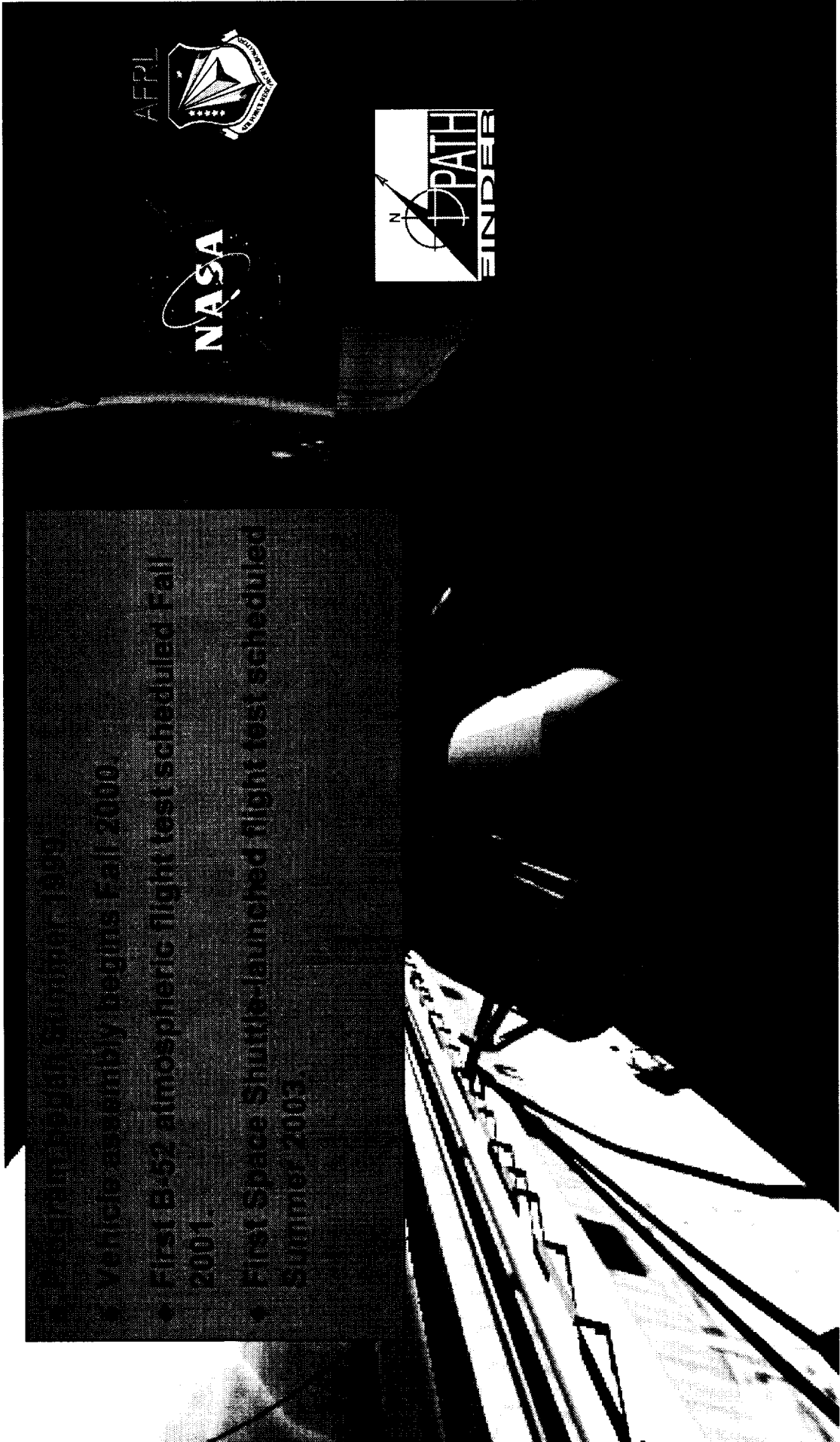


X-40A Flight Test Vehicle Summer 00





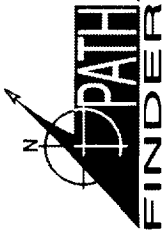
Boeing X-37



- Vehicle assembly begins Fall 2000.
- First B-52 atmospheric flight test scheduled Fall 2001.
- First Space Shuttle-launched flight test scheduled Summer 2003.



Successfully Achieve Orbit and Return to Earth Safely

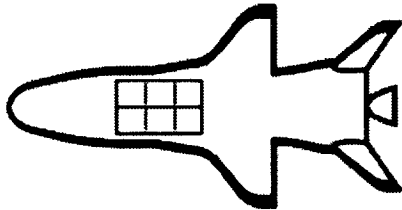


Blazing the Highway To and From Space

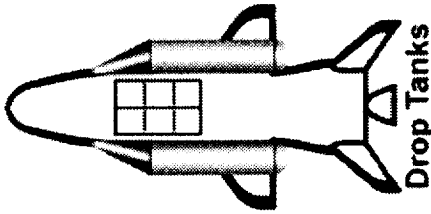


X-37 Configuration Modification Options

Baseline

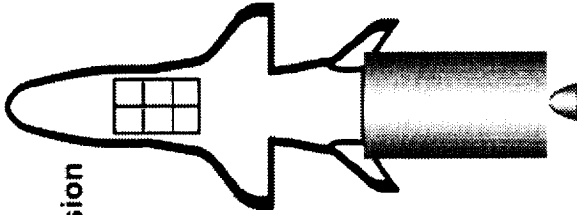


Increased Propellant

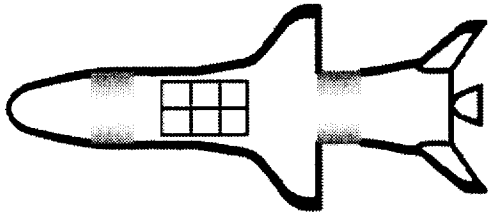


Drop Tanks

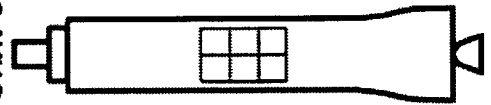
Auxiliary Propulsion



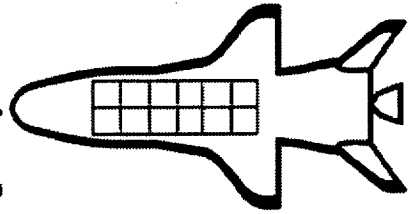
Fuselage Plugs



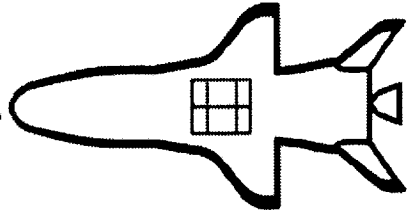
On-Orbit Only



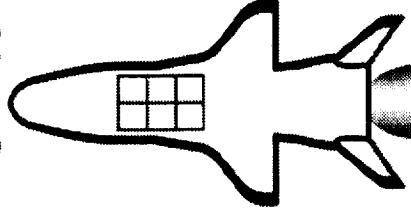
Large Payload Bay



Small Payload Bay



Main Engine Upgrades



Expansion-Deflection Nozzle